PERVIOUS VS. IMPERVIOUS PAVEMENT:
AN ENGINEERING APPROACH TO COST EFFICIENCY

by
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ABSTRACT

Will VanLandeghem:
Pervious vs. Impervious Pavement: An Engineering Approach to Cost Efficiency
(Under the direction of Dr. Cristiane Surbeck)

This research attempts to make a comprehensive comparison between the relatively new breed of pavement, pervious concrete, and asphalt, a more popular and accepted pavement type. Pervious concrete is mainly used as a pavement surface for green purposes; however, this thesis delves into the possibility that pervious concrete may be able to offer benefits that allow the green alternative to be cost efficient as well. The comparison will be made over the entirety of the surface life including each pavement design and the materials used, the surface drainage, and the maintenance of each. The pavements were analyzed from a real parking lot while some of the characteristics and values were idealized for the purposes of the research, but the results could offer motivation for future contractors to utilize both a green and cost effective pavement.

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LIST OF VARIABLES AND ABBREVIATIONS

A	In Eq. 1, this is the area of the tributary drainage region in acres.
ASTM	The American Society for Testing and Materials is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.
C	In Eq. 1, this runoff coefficient is used for different surfaces with different degrees of porosity.
CN	This is the SCS runoff curve number used in Eq. 11.
D	In Eq. 10, the inside diameter of the infiltration ring is measured in millimeters.
D	This is the diameter of the pipe computed in Eq. 11.
HDPE	High-density polyethylene pipe is a durable, flexible, and lightweight pipe material that is used for the stormwater drainage in the Law School parking lot.
i	In Eq. 1, the average rainfall intensity in inches per hour is taken from intensity-duration frequency relationships for a specific return period.
I	The infiltration rate used in Eq. 10 is in units of millimeters per hour.
IPF	The Indoor Practice Facility is on the campus of The University of Mississippi, and sits next to a parking lot which utilizes pervious concrete.
K	In Eq. 1, this is the factor for units used and is 1.0 for U.S. customary units and 0.28 for SI units.
K	In Eq. 10, this factor is used to convert kilograms, millimeters, and seconds to the infiltration units of millimeters per hour. K is 4,583,666,000 for SI units, and 126,870 for U.S. customary units.
L	In Eq. 11, the hydraulic length of the watershed is the longest flow path that the water travels over the ground surface before draining into the drainage system.

M	In Eq. 10, the mass of the infiltrated water, in kilograms, is used to measure the infiltration of the surface pavement.
m_D	Manning's unit factor is 2.16 for U.S. Customary units and 3.21 for SI units. It is used in Eq. 11 to design the diameter of the pipe for stormwater drainage.
n	Manning's roughness coefficient used in Eq. 11 can be found in Table 5.1.1 in Mays' *Water Resources Engineering* text book.
PC	For simplicity, pervious concrete will be referred to with this acronym throughout the thesis.
Q	The peak flow rate is given in units of cubic feet per second.
S	This is the average slope of the watershed used in Eq. 11.
SCS	The U.S. Department of Agriculture Soil Conservation Service is now called the National Resources Conservation Service but will be referred to by its original name for simplicity.
SWMM	The EPA program stands for Storm Water Management Model and is used throughout the world for planning, analysis, and design related to stormwater runoff, combined and sanitary sewers, and other drainage systems in urban areas.
S_0	The slope of the pipe being designed is required to solve Manning's equation, Eq. 11.
t	In Eq. 10, the time required for the measured mass of water to infiltrate into the surface pavement measured in seconds.
t_c	The time of concentration for each of the possible critical flow paths.
t_f	The flow time of the immediate upstream sewer.
t_0	The inlet time for the subcatchment is the overland flow inlet time if the upstream subcatchment is no more than one sewer away from the sewer being designed, otherwise it is the total flow time to the entrance of the immediate upstream sewer.

CHAPTER 1: INTRODUCTION

Mankind's quest for paving roadways can date all the way back to around 4000 B.C.E. in the Indian subcontinent and Mesopotamia, the birthplace of civilization. It was well before the invention of the wheel that humans started using rudimentary materials like stone to pave pathways simply to keep travelers' feet from sinking in mud when it rained. As transportation began to evolve, and heavy wagons and payloads began to increase, so did pavement technology. The Romans were the first to use a layered road system for moving military troops and supplies, and it was not until the early 19th century that more contemporary materials like sand and crushed aggregate were used as pavement that was laid down with machinery similar to what is used today. However, even in the past century, pavement methodology has continued to advance and evolve as newer, more efficient approaches to pavements have surfaced. Although paved roadways are one of the most basic human inventions behind fire, pavement design is still a dynamic concept that is ever evolving and ever changing.

For the past couple of decades in the green community, paving roadways, sidewalks, and parking lots with pervious pavement has come on the scene as a new pavement technology to improve three different aspects: the recharging of water tables, the reduction of runoff pollution, and to help control overrun storm water collection systems. Because this green pavement is still in the early stages of discovery, it is not widely considered as a better, more efficient alternative to the tried and true method of using impervious asphaltic pavements. The University of Mississippi took it upon itself to begin a trend of using pervious concrete (PC) in downhill sections of recently built parking lots on campus. The Facilities Planning Department has utilized the green pavement in sections of both the new Law School parking lot, as well as the new parking lot for the Indoor Practice Facility (IPF). The University's original rationale for using this new pavement system was not driven entirely by environmental friendliness, however. There were legal issues involved, as stormwater runoff from the University roadways was not being properly collected in storm drains and was running off into a privately owned lake, throwing off the lake's natural equilibrium. This raises a point, however, that pervious pavement may provide more benefits than just avoiding neighboring lawsuits and initiates the call for a further look into this new pavement technology.

Since the conversation surrounding permeable pavement for the University began by addressing overrun storm water drainage, it seemed pertinent that a comparison should be made between permeable and impermeable surfaces not only just with performance but also in terms of cost efficiency. This research attempts to look into the costs associated with the different materials each of the two pavements utilize, the costs surrounding the different piping needed in accordance with the different amounts of water runoff for the two pavements, and finally a comparison of the costs involved with maintaining these two different kinds of pavements.

The research will look at the southwestern section of the Robert C. Khayat Law School parking lot (see Figure 1) and will compare an idealized version of the PC and asphalt pavements that are in place with the same section of the lot under the assumption that it is paved only with impervious asphalt.

Figure 1. Satellite View of the Idealized Section

CHAPTER 2: BACKGROUND

2.1 Introduction

In order to understand the reasoning behind the testing methods and procedures conducted for this research, a summary of the information collected throughout the process must be illustrated. Much of the actual research and learning that was accomplished over the course of this study will be presented in this chapter. The following sections will attempt to give some background and create a common ground for knowledge on the subject before the methods of the thesis are discussed.

2.2 Urbanization

The sole reason pervious concrete started to become introduced as a legitimate pavement alternative is due to a heightened awareness of urbanization. The challenges that an urbanized world brings about include “changes to the hydrological cycle including radiation flux, amount of precipitation, amount of evaporation, amount of infiltration, increased runoff, etc.” (Mays, 2011). When an undeveloped area starts to become urbanized, pavement is laid down and buildings are erected which prevents water from infiltrating into the soil, as it would do in a natural state. A demonstration of this phenomenon is shown Figure 2.

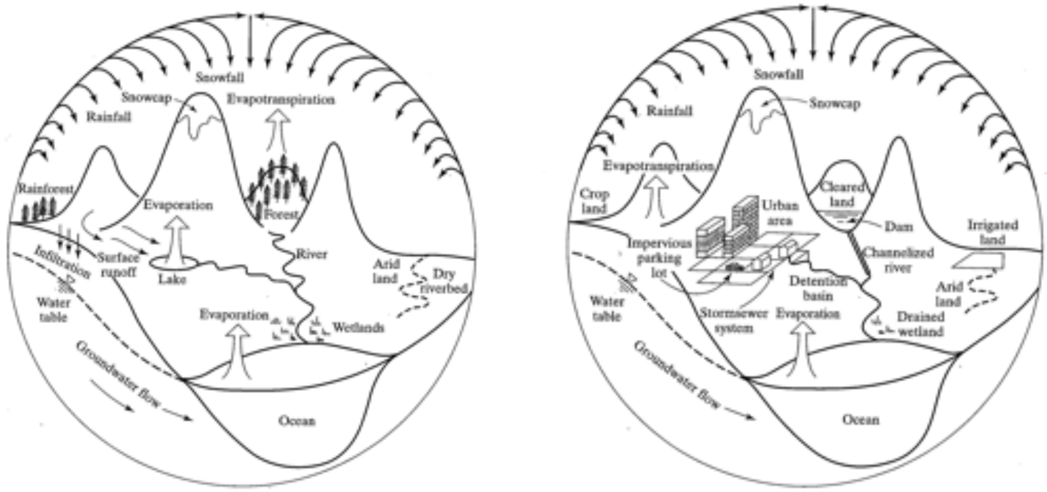

Figure 2. Showing Undeveloped vs. Developed Water Cycles (McCuen)

The picture on the left represents the undeveloped state where there is healthy infiltration and recharging of the underground water table. The picture on the right shows less groundwater flow but does show structures like detention basins and other stormwater systems. It was not until larger cities began to start arising in the 19th century when engineers and city developers began to realize that urban runoff needed significant attention. Today, design regulations for a given plot of land call for runoff to be the same as it would in an undeveloped state. In order to meet this requirement, different stormwater management methods are put into place like detention ponds. "The use of permeable pavement, in place of traditional asphalt, or concrete, has been shown to decrease surface runoff volumes and substantially lower peak discharge" (Bean, 2007). However, the use of this pavement technology is not exactly commonplace because questions still remain surrounding its efficiency.

2. 3 Materials and Installation

To properly compare the two pavement systems, a general understanding of the fundamental differences in materials used in each mix design must be considered. Since pervious concrete (PC) is a specialized pavement, different materials were involved with its mix design to allow for a pervious surface. This means that a simple comparison to asphalt would be like comparing apples to oranges. This section will outline the different designs that could have been used for the Law School parking lot and will offer the base price estimates used by contractors in Oxford. The asphalt section will be analyzed, followed by the pervious section of the lot. This section will also include some insight into the installation process of each pavement type and the troubles associated with these price estimations.

Lehman-Roberts Company is a pavement contracting company based out of Memphis, TN that mostly deals with asphalt pavement. They have been in charge of many pavement projects around the Mid-South, including the asphalt section of the Law School parking lot. The company's director of southern operations, Michael Ellis, P.E., made a large contribution to this research by providing the Law School project summary sheet, the proposal contract specific to the job, as well as a multitude of other useful bits of information. The following information on the asphalt section of the parking lot is courtesy of Mr. Ellis.

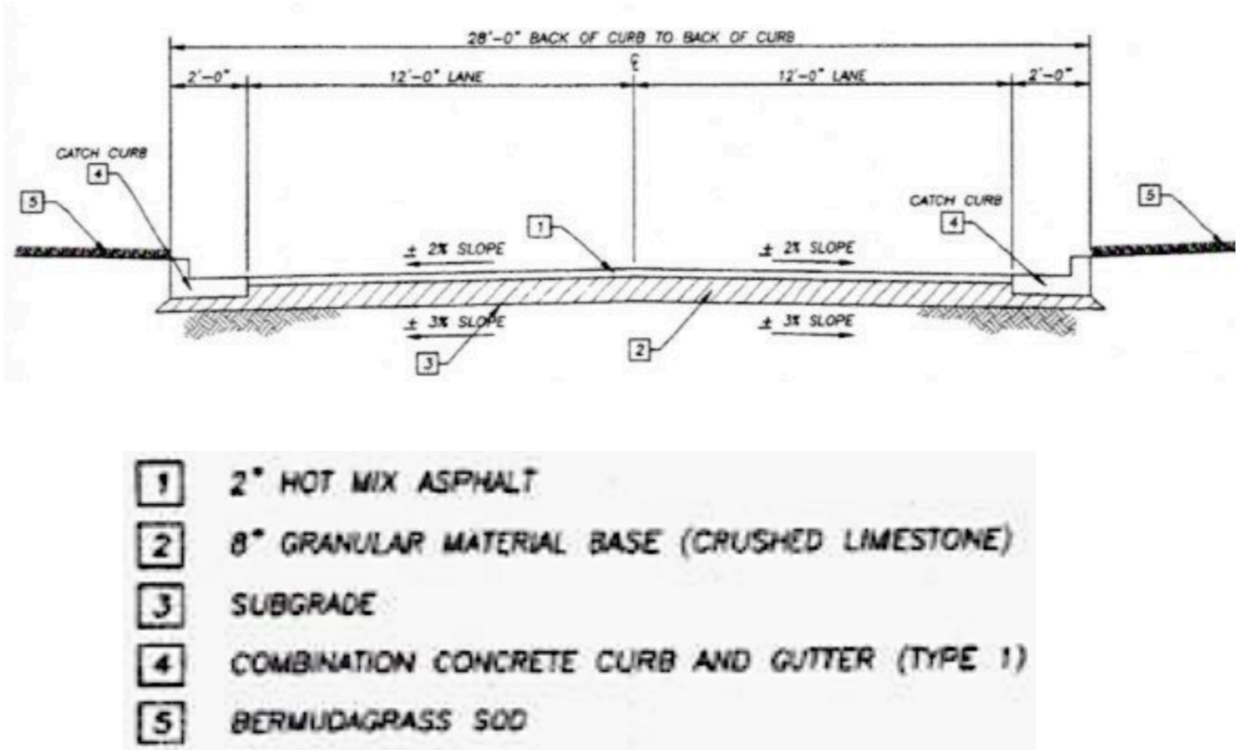

Figure 3. Cross Section of Asphalt Pavement (Lehman-Roberts)

There is an 8-inch gravel paving base supporting 2 inches of hot mix asphalt (Figure 3). Hot mix asphalt is about 95% aggregate bound together by asphalt cement, which is a product of crude oil. The asphalt for this specific project was estimated to cost \$72 per ton of mix used. This price was subject to change due to the fluctuating price of petroleum. At the time the proposal was published, the MS Bituminous Index was \$397.14 per ton. In order to manipulate the values for comparison, a density for the specific asphalt mix design must be known. This value was quoted to be 110 pounds per square yard per inch of thickness. These values, along with the area of asphalt pavement combine to estimate the cost of asphalt for comparison.

Specific prices for the PC materials were not as readily available, however, a breakdown of the materials used was taken from the contract proposed by Lehman-

Roberts. A layer of geotextile fabric serves as the base for the design, which is topped by 8 inches of a #57 stone base. 8 inches of PC sits atop the stone base, which serves as the pervious top surface. A general mix design for PC proposed by B&B Concrete in Tupelo, MS shows the design in percent by volume.

Table 1. Mix Design of PC (B&B Concrete)

Pervious Concrete Mix Design

Materials	% by volume
Limestone	40.6
Cement	22.0
Air	20.0
Water	11.7
Fly Ash	5.7

The pricing of these materials seemed to have a degree of uncertainty. Kent Howell, with Endevco, quoted that PC costs around $75-80 per square yard, however, this price included the geotextile fabric, the stone base, as well as the PC. This value is said to be approximately twice as large as the price for all the layers needed for asphalt. However, this comparison is not accurate since the price provided for asphalt does not include the base layers. Since a breakdown of the cost of each material in the PC design could not be obtained, another pricing estimate had to be used.

Cary McGonagill, who is a local Oxford contractor, was able to offer some additional insight for the pricing. He says that in general, PC is more expensive than asphalt, however, this estimate is variable depending on the use of the parking lot. For instance, lightweight PC is about 25 to 35% more expensive than its lightweight asphalt counterpart. As the pavement needs to support more and more weight, PC becomes more and more affordable almost to the point of being the same price. Having things like loading docks and outdoor garbage dumpsters on the parking lot would control the design load of the pavement because these items would require that the lot surface support heavy semi trucks and garbage trucks. The Law School lot does not have either, so lightweight PC is used to pave the surface.

An estimation of the costs associated with the labor involved with each different pavement type was supposed to be included in the scope of this research, but too many variables played a factor in trying to make an accurate comparison. Being able to compare the entire life of the pavement, including the different methods for construction, would be ideal because this would mean that every aspect of the two different pavements could be put under the microscope. Everything from wages to the machinery required, to the types of weather restrictions under which each can be worked on would have to be considered, and since this research focuses on the two pavement types and specifically, their hydrological effects, a detailed look into the construction management side of this project proved to be too far removed. Cary McGonagill offered the most helpful insight into the basic difference between the construction of PC and asphalt lots. He said that PC requires more hand skill to put down because a precise installation of PC is essential to having good infiltration rates in the future. This requirement means that PC is more expensive to lay than asphalt because the latter can be put down with a machine. Upon first glance, machine work would seem to be faster and more efficient. However, Michael Ellis hinted at the parking lot being more expensive to pave with machinery because the lot is so much more confined than a regular road would be. Details like this make the estimation nearly impossible and ultimately lead to the abandonment of the construction comparison for this research. Even though the scope for this project is not all-inclusive, it will be more accurate because of all the uncertainties surrounding the construction side of the project. The installation, including equipment and labor, will not be considered from this point forward.

After discussing the different materials involved with PC and asphalt, the base numbers can be compared. Although there are many layers involved with both PC and asphalt, the topping material will be compared in pricing. The asphalt has a 2 inch hot mix asphalt topping priced at $72 per ton when the MS Bituminous Index is constant. This value will be compared to the 8 inches of PC whose square yardage cost is about 25 to 35% more than a hot mix asphalt square yardage price. While PC is placed mostly by hand and asphalt is installed with machinery, a comparison of the price for installation will be taken out due to uncertainty.

2.4 Infiltration Rates

Taking a look at infiltration rates is important for this comparison simply due to the fact that infiltration is the fundamental difference between the two types of pavement. Pervious concrete has the ability for stormwater infiltration, and asphalt does not. Since this research tracks the path of stormwater from the point of impact on the surface of Earth to the disposal of the water through stormwater drainage, testing procedures must be carried out in order to quantify the amounts and locations of the water within the specified scope of the Law School parking lot.

A computer program, developed by the EPA called Stormwater Management Model (SWMM), is used to estimate the characteristics of the different subcatchment areas around the parking lot and where the water flows. See Figure 4 for the modeled subcatchments of the Law School using SWMM.

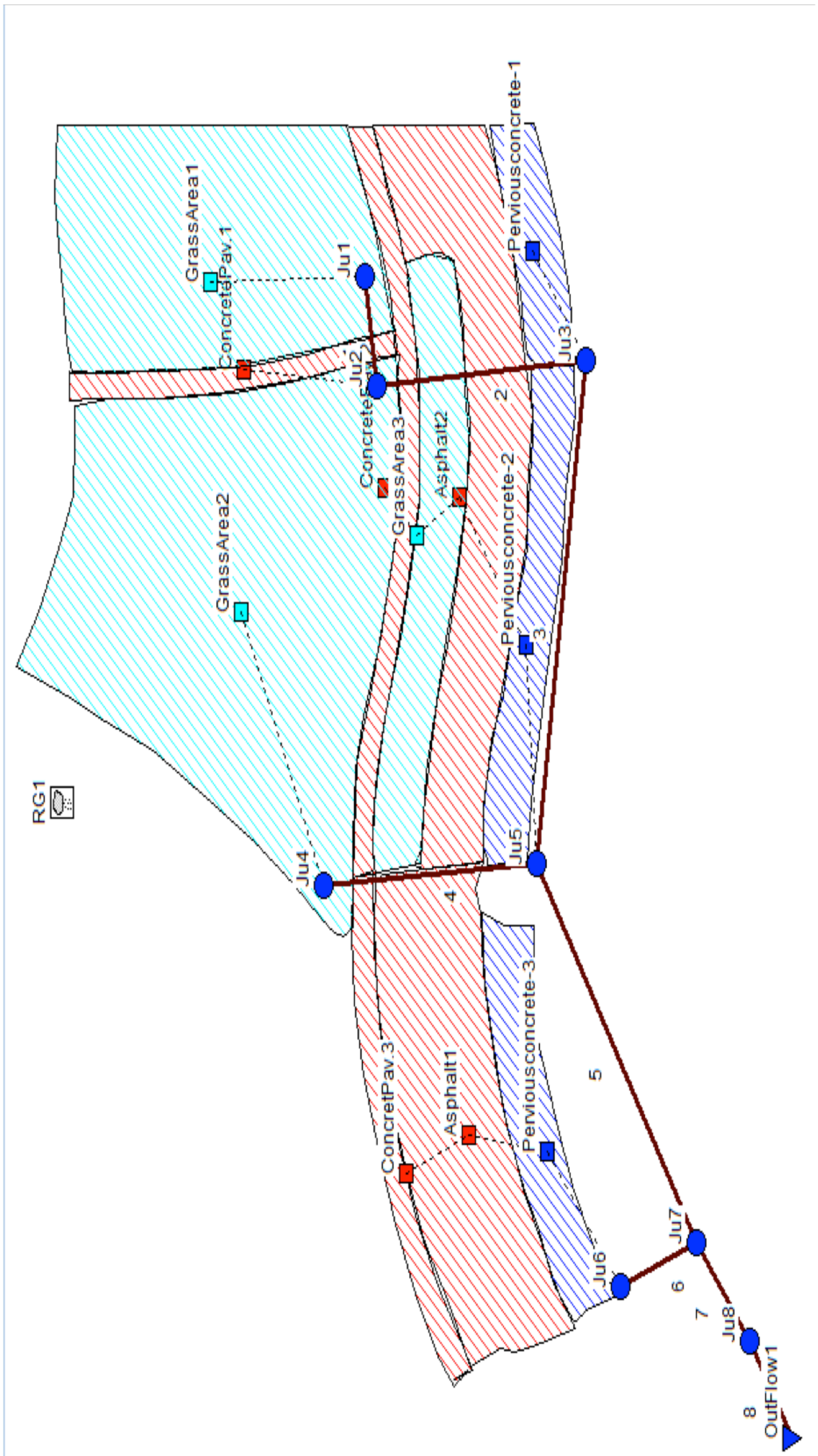

Figure 4. Subcatchment Layout from SWMM (Courtesy of Liya Abera)

This information is pertinent to determine peak flow in the stormwater drainage pipes and ultimately what size pipe is needed. The variability in diameter of the drainage pipes is a concept in this research that is addressed, and it is this difference in size that has the unique ability to create influential differences in pricing for the construction of the parking lot.

In order to use infiltration rates in this research, an experiment must be conducted to accurately estimate the infiltration of the PC in the parking lot. Understanding the infiltration rates usually helps to determine whether the concrete is contributing to the design drainage requirements set forth by city ordinances. Since The University of Mississippi is funded by the state, however, it does not abide by the requirements set by the City of Oxford. This means that calculations were not conducted to determine whether or not the design of the parking lot lives within these requirements, but to determine characteristics of the concrete such as the Curve Number value and the runoff coefficient used in the Rational Method. In order to calculate runoff, a test must be made to measure the infiltration rates. The American Society for Testing and Materials (ASTM) has developed a standardized testing method. By standardizing the testing methods, ASTM allows data from all different kinds of mix designs and materials to be compared along the same plane. Out of all of the different surfaces in the idealized section of the Law School parking lot, which include, asphalt, concrete, grass, and PC, the infiltration properties of PC are the most unknown and disputed. Therefore, an ASTM Infiltration Rate test is conducted for the in-place pervious concrete in the Law School parking lot.

2.5 Drainage Pipe Estimation

To understand the bulk of this research, one must first understand the purpose and methods behind stormwater management and drainage systems. When designed correctly, storm drainage ensures the longevity, safety, aesthetics, and maintainability of the system served (Urbonas and Roesner, 1993). Upon first glance, stormwater drainage systems perform a very simple task: removing stormwater from the streets and permitting the transportation arteries to function during bad weather (Urbonas, 1993). This of course seems obvious even to the layman; drainage systems drain water when it rains. The different methods and techniques of how stormwater is disposed of are not commonly known, however. Urbonas and Roesner continue by pointing out that drainage systems also control the rate and velocity of runoff. This concept of velocity control is the main component behind pipe design because the peak amount of water flowing at a certain time is the main factor in determining the required size for pipes.

The purpose of estimating drainage pipe sizes for this research stems from the theory that PC allows for water to infiltrate into the ground at a certain rate, decreasing runoff over a specific area like a parking lot. When runoff is decreased, pipes become smaller, and money is saved. A question of precisely how much the runoff and piping size will be decreased still stands. There are many variables that enter into answering this question, including factors pertaining to the runoff surface, the sewer catchments, and even the piping that is laid underground. All these factors and more combine to answer the simple question of how much runoff changes.

One method of determining runoff is the Rational Method. “Traced back to the mid-nineteenth century, (the rational method) is still probably the most popular method used for the design of storm sewers" (Yen, 1999). This method allows for one variable, the peak runoff rate (Q), to control the design of the drainage systems. It is this simplicity that allows for the rational method to still be the industry standard for sewer design today. The stormwater runoff peak is estimated by the formula,

$$Q = KCiA \tag{Eq. 1}$$

where Q is in ft^3/s, K is 1.0 in U.S. customary units, C is the runoff coefficient which can be found in Table 13 and 14 of the Appendix, i is the average rainfall intensity in in/hr from intensity-duration frequency found in Table 15 of the Appendix, and A is the area of the tributary drainage area in acres. The intensity-duration relationship allows for the intensity to be determined from a specific return period in years and storm duration in minutes. Since the University property is not built under Oxford building ordinances, the return period of the design storm must be assumed. The value is assumed to be 25 years to be conservative. The duration used in the intensity chart is taken as the time of concentration (t_c) calculated for the drainage area. An accurate estimate for t_c offers some issues for further calculations. In a typical catchment area, there are multiple sewers that collect runoff. This means that water arrives at drainage pipes at different times. Thinking practically about this calculation of t_c is imperative because simply plugging in estimated times to a formula will not result in an accurate design. Assuming that the total amount of runoff through a pipe flows at one time will lead to a gross overestimate for the design of pipe sizes. In order to prevent this overestimation, there is a process for finding the correct t_c.

In order to account for the time it takes for water to flow over the land surface, "the time of concentration to any point in a storm drainage system is the sum of the inlet time, t_0, and the flow time in the upstream sewers, t_f, connected to the catchment" (Mays, 2011). Figures 5 and 6 will be used to explain this concept in greater detail so that there can be a comparison made between the peak flow rate of a pipe collecting runoff from one sewer (Figure 5), and the peak flow rate of a pipe collecting runoff from two sewers (Figure 6). Although the Law School parking lot utilizes a more complicated design, a comparison of one and two sewers will be sufficient for the purposes of explanation.

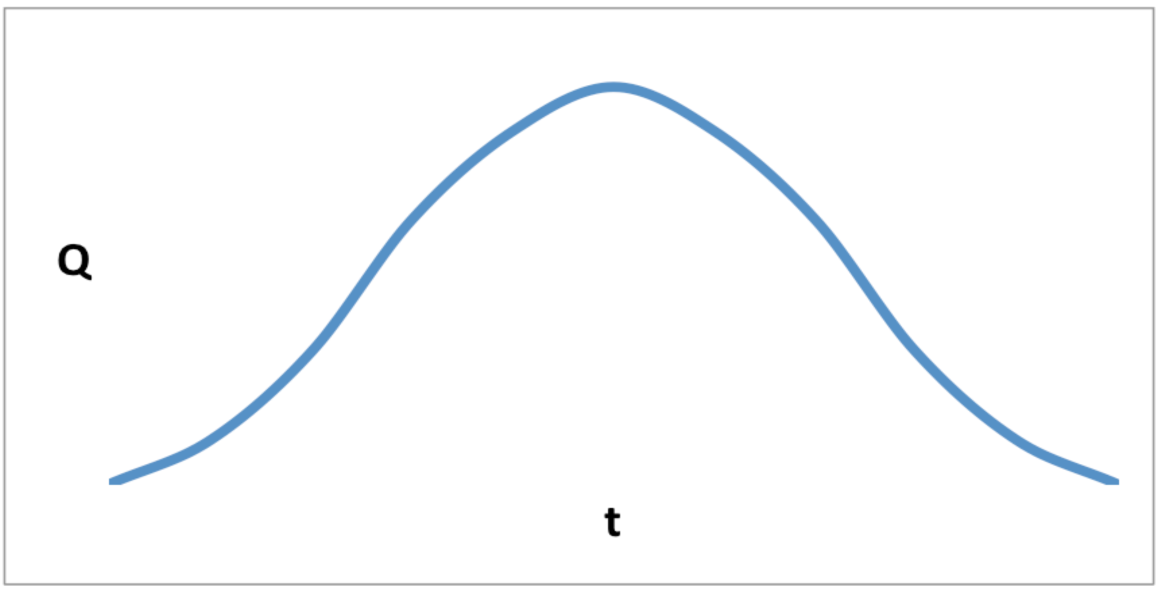

Figure 5. Illustration of Peak Flow Rate in a Pipe vs. Time from One Sewer

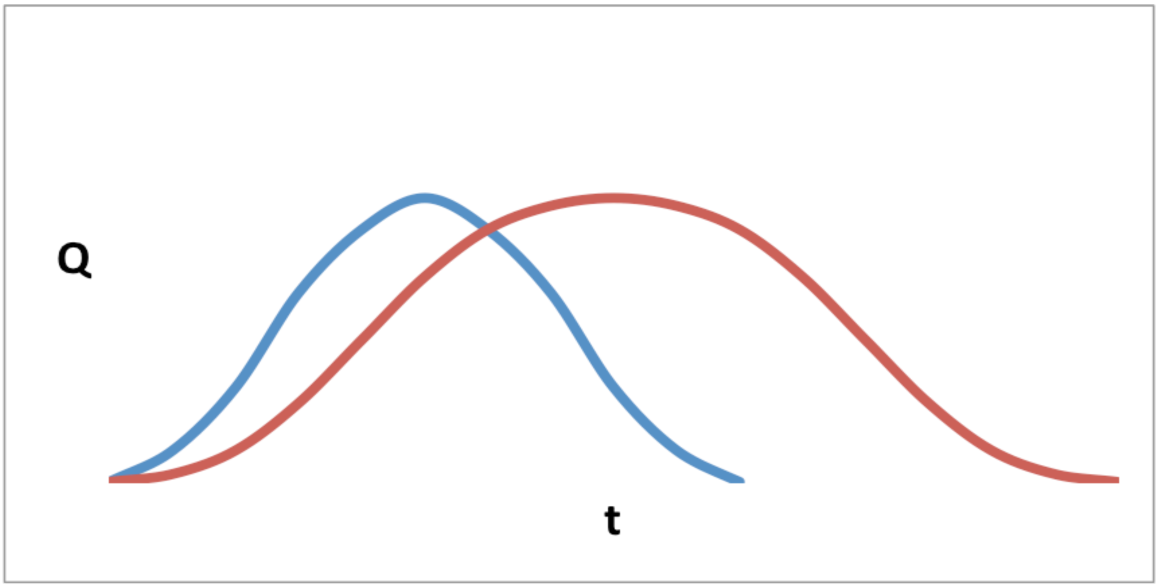

Figure 6. Illustration of Peak Flow Rate in a Pipe vs. Time from Two Sewers

Figure 5 shows that all of the water from one sewer flows through one pipe at one time. Figure 6 shows water flowing from two sewers into one pipe. The peak flow from each sewer passes a single point in the pipe at different times, and for design purposes, the peak flow inside the pipe is not the sum of the peak flow from each sewer. The inlet time and upstream flow time used to calculate t_c cannot be determined until the sewer flow velocity is found. The flow velocity in turn cannot be found until the size of the pipe is computed from the peak flow rate, which is found using t_c. The calculations for t_c comes full circle where multiple values are dependent on each other, so calculations start to become an iterative process.

Once the required pipe size is calculated, the pricing of the stormwater drainage pipe can be estimated. The blueprint drawings for the Law School, as seen in Figure 7, indicate that high-density polyethylene (HDPE) pipe is used.

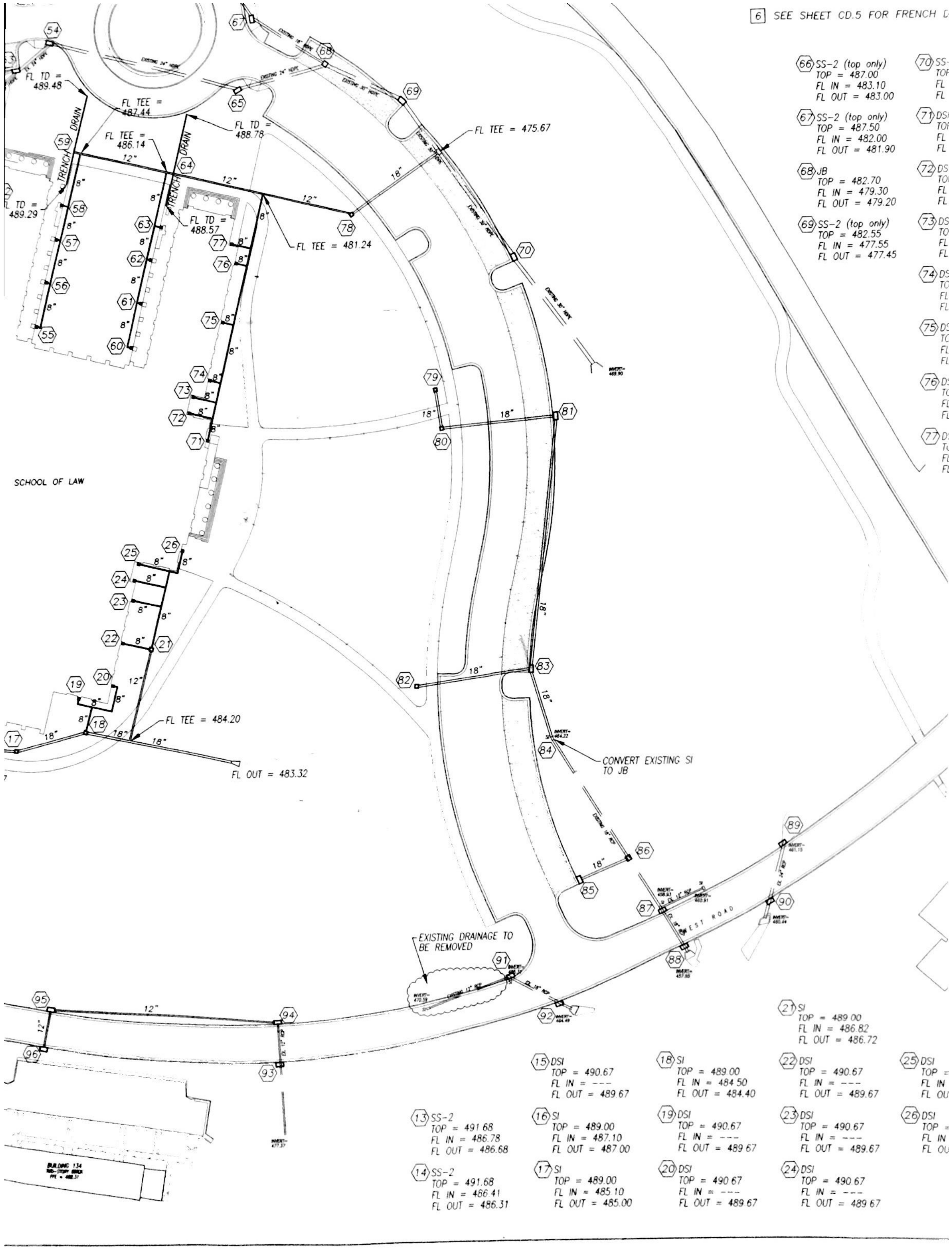

Figure 7. Law School Pipe Layout with Sewer Labels

The price for this piping came from a combination of two sources, which were used in tandem to estimate the price for the stormwater drainage. The costs for the HDPE pipe for Tupelo, MS are charted below.

Table 2. Price Estimates for HDPE Pipe (Simoneau and RSMeans)

HDPE Pipe Costs for Tupelo, MS

Diameter (in)	Price ($/LF)
12	39.59
15	44.45
18	49.39

Gathering the information surrounding the different pipe sizes and the costs that go along with these differences engulf the main focus of this research. The original assumption for this thesis was that utilizing PC would slow the runoff enough to allow for much less stormwater structures under the lot. Ian Banner, the director of facilities planning and the architect for the University of Mississippi, confirmed this assumption by stating that reducing the engineering structures was a contributing factor in the decision to use PC. The price difference in piping presumably would dwarf the cost difference of materials and maintenance down the road, however, that assumption remains to be confirmed.

2.6 Maintenance

While infiltration and drainage estimation may require the bulk of the calculation for the comparison, this section will attempt to compare the two types of pavements over their lifetime by illustrating the information received from the contractors. Making a long-term analysis will ensure that the comparison of the two types of surfaces is as all-inclusive as possible. However, it turns out that making a direct comparison of maintenance between the two different pavements is difficult. Part of the problem stems from the two pavements experiencing very different issues over their lifetime simply due to the difference in the materials and mix design for each. Another part is that pervious concrete has not been studied for nearly as long as asphalt, so there are still many questions surrounding this new pavement type in the industry. Maintenance surrounding asphalt will be discussed first, and a summary for PC will follow.

Asphalt has both pros and cons as a pavement option, but it is the most commonly used road surface because it has the best combination of strength and low cost. According to Michael Ellis with Lehman-Roberts Company, asphalt has a lifespan of about 20 years when no maintenance is carried out. This span is an average, because much of this value depends on how much daily traffic the surface experiences as well as how the road is used. High traffic volumes and heavy payloads will contribute to the deterioration of the road surface and strength. Since the road in question is a parking lot, the daily traffic volume will be very low compared to busy highways. Ellis points out that the biggest problem an asphalt surface, like the Law School parking lot, will face is moisture. Moisture will get under the layers and cause base failures that will lead to cracking and potholes. Ellis outlines another problem specific to asphaltic parking lots, which is petroleum leaks. Cars that are parked for an extended period of time will leak gasoline onto the asphalt surface. This puddle will proceed to strip the top layer off the asphalt topping, exposing the rest of the surface. These issues call for maintenance throughout the life of the asphalt, so a consultation with T.L. Wallace Construction, Inc. was conducted to obtain a price estimate for the maintenance of the asphalt surface.

Jimmy Kendrick, vice president of the asphalt division for T.L. Wallace Construction, provided some understanding of the details involved with maintaining asphalt. He states that the secret to a healthy, long lasting road surface is the right treatment for the right pavement at the right time. Every job is different, so there are many variables that come into play when it comes time for fixing up a road. In general, the surface issues need to be addressed before they even start. If done correctly, a microsurfacing job can prolong a road by 10-15 years. Microsurfacing is the least expensive maintenance alternative provided by Mr. Kendrick. A microsurfacing job would need to be done every 7-10 years, and around 2 jobs total are typical for the lifespan of a road. Mr. Kendrick quoted this job to be about $2 per square yard. The problem is this overlay cannot be used on PC.

Like much of the research, solid information for PC was hard to obtain. The biggest problem with the maintenance of PC is that it has not been around long enough to see what kind of effects age has on the pavement. Kent Howell claims to have seen PC in Mississippi for only the past 5 or 6 years. Testing and theories can only go so far, so if there has not been permeable concrete in use for over 20 years, it makes the comparison with asphalt very difficult. The best source for the maintenance of permeable pavements came from a study from Floris Boogaard (2014) called, “Effect of Age of Permeable Pavements on Their Infiltration Function: Effect of Age of Permeable Pavements”. This article analyzed permeable pavements in Australia and the Netherlands over a certain number of years. 12 years was the longest time period a pervious pavement had been tested. After 8 to 12 years, Boogaard's research showed that permeability for a resounding majority of the test sites showed acceptable rates of infiltration. The main issues that stunted the pavement's performance in this study included clogging, poor construction practices, and out of date maintenance practices.

Since no practical maintenance techniques for PC are in place, pricing for the maintenance was impossible to pinpoint. A discussion can be made surrounding likely issues PC will deal with. Ian Banner states that the vacuuming for the clogging due to sedimentation build up was an unexpected hiccup that accompanied the PC maintenance. After a certain amount of time, the clogging will completely impede the infiltration of runoff, rendering the pervious nature of the concrete useless. Banner goes on to say that he does not know if the declining infiltration rates are more related to clogging or poor construction techniques. Either way, vacuuming of the pervious section of the parking lot has yet to be accomplished at the University.

Another issue with pervious concrete is that it could add to the deterioration of the asphalt next to it. PC will always have an impervious pavement next to it because the water is merely supposed to collect in the pervious area, and due to the pervious nature of PC, heightened moisture issues could arise for the neighboring asphalt. Jimmy Kendrick says that the runoff that infiltrates through the pervious concrete could pool up and collect under the asphalt causing more moisture issues than normal. He continues by admitting that only time can confirm or deny the proposed issue at this point. A positive point for PC is that petroleum will not strip the topping. One of the biggest benefits for PC is that gasoline, oil, and other pollutants from cars infiltrate into the PC and get trapped in the void spaces, so it will not have enough time to stay on the topping and do any damage. After this discussion, an accurate weight of these pros and cons for the maintenance of PC will unfortunately go unknown for this research.

2.7 Conclusion

While some of the research for this thesis seemed to work out as originally planned, much of the information this work wanted to uncover proved to be very difficult to find. Trying to include a detailed comparison of the entire life of the two pavements may have been a bit ambitious. The missing bits of information for this chapter are primarily missing price estimates for PC. The issue is that if these prices are not known or readily available, it is impossible to perform a test to find it out. The known estimates will carry the comparison for the remainder of the research.

CHAPTER 3: METHODOLOGY AND DATA COLLECTION

3.1 Introduction

After consultations with experts were conducted to find out how to price the materials and maintenance for each pavement type, calculations were made to use these numbers for an easy comparison. Fieldwork was required to identify the production of the pervious concrete for reference purposes. Calculations were made to identify the difference in pipe sizes for each parking lot type. The research is set to compare a parking lot that utilizes PC and a lot that is completely paved with asphalt. This means that many of the calculations will be carried out twice, once for each case. This section will list the steps required for each of the different tests or calculations made throughout the research process.

3.2 Materials and Maintenance Cost Estimation

Since the values for the different aspects of pricing were for the most part outlined in the previous chapter, the process of how these values were manipulated for comparison is outlined in this section. Many of the price estimates are based on the size of the job, so a breakdown of the area used for this research will be analyzed first, followed by the price breakdown of the materials and finally maintenance.

The entire area of the lot in question is around 1.6 acres. The driving surface is about 35.0% of this area with the rest of the parking lot consisting of the runoff subcatchment areas like the grass lawn and the sidewalks that surround the Law School. A satellite picture will clarify which area of the lot is being analyzed (see Figure 1 in Chapter 1). Although some of the lot is covered by shadows, the downhill parking bays stand out in the picture because that is where the PC is laid. PC stands out as a lighter color than the dark asphalt. Around 32.3% of the driving surface is pervious concrete, making asphalt around 67.7% of the driving surface. This means that most of the parking lot is asphalt, but the pervious section is strategically laid in the downhill portion of the lot. According to Kent Howell from Endevco, the pervious pavement would only be utilized in the area of the lot where water collects. This is done so that the water will have time to infiltrate through the pavement. Having pervious concrete for an uphill section of the lot would cause unnecessary expenses. Since the driving surface is roughly 24,437 square feet, the PC has an area of about 7,893 square feet and about 16,544 square feet of asphalt. These values will become very vital since the price estimates are per volume.

The price estimates for the pavement materials are based off the price proposal for asphalt provided by Michael Ellis and Lehman-Roberts Co. This price is given in dollars per ton, so the process requires steps that will convert the values into workable prices.

1. Convert the density of asphalt from units of pounds per square yard per inch of thickness to tons per cubic yard.

$$110\, lb/(yd^2 * in) = 1.92\, tons/yd^3 \qquad \text{(Eq. 2)}$$

2. Multiply the price in dollars per ton by the new density value, and a more workable figure should come out in units of dollars per cubic yard.

$$\$72/ton \times 1.92\, tons/yd^3 = \$138.24/yd^3 \qquad \text{(Eq. 3)}$$

3. Once the price value was found, the volume of the hot mix asphalt must be computed. Since the area of the paved surface and the depth of the asphalt was known, a total price for the hot mix asphalt was found.

$$102.1\ yd^3 \times \$138.24/yd^3 = \$14{,}118.68 \qquad \text{(Eq. 4)}$$

4. The same price estimate calculation was made for the parking lot that is all asphalt. The only difference was the volume of asphalt.

$$150.9\ yd^3 \times \$138.24/yd^3 = \$20{,}854.57 \qquad \text{(Eq. 5)}$$

5. Since the best price estimation for PC was given as a reference to asphalt, the upper boundary of Cary McGonagill's PC price estimation of 35% more than asphalt was used.

$$\$138.24/yd^3 \times 1.35 = \$186.62/yd^3 \qquad \text{(Eq. 6)}$$

6. A similar calculation for total price is now used, but the volume of PC is now used instead of asphalt. The square footage of PC is much less than asphalt, but it has 4 times the depth, so the volume of PC topping used will be quite large.

$$194.9\ yd^3 \times \$186.62/yd^3 = \$36{,}370.94 \qquad \text{(Eq. 7)}$$

These values will be analyzed in the next chapter, but the numbers are quite surprising. The square yardage of each pavement type is rather misleading because the volumes of each pavement are different. Where PC is a third of the total driving surface area, it makes up over half of the total volume of topping used. The difference in materials used may prove to be a very influential figure for comparison.

After the price of materials was broken down, a look at the maintenance was considered. While there may be many different types of maintenance methods for asphalt surfaces in practice, the method chosen for this research was microsurfacing preformed by T.L. Wallace. Since the recommended number of jobs over the lifetime of the asphalt was considered, a price for the maintenance was acquired.

1. To get the price of one job, the price per square yardage was multiplied by the area of asphalt. This value was then doubled to get a price for the lifetime of the asphalt.

$$\$2/yd^2 \times 1{,}838.2\ yd^2 = \$3{,}676.44 \quad \text{(Eq. 8)}$$

2. This same calculation is done for the completely asphaltic parking lot, and the only difference is the area of asphalt.

$$\$2/yd^2 \times 2{,}715.2\ yd^2 = \$5{,}430.44 \quad \text{(Eq. 9)}$$

While the maintenance of asphalt was computed, a number value for PC was still impossible to find. A comparison can still be made as far as maintenance is concerned, and a discussion of how this is possible is explained in the results section, although it is a rather weak comparison compared to the difference in materials and underground stormwater drainage. The methods and testing for the drainage system begins in the next section of this chapter.

3.3 Infiltration Rates

The infiltration rate tests were conducted in the parking lot across from the IPF. Since the research is looking at an idealized pervious pavement in the Law School lot, the IPF lot is used because it is more recently paved and is therefore less clogged. Infiltration in the Law School parking lot is significantly less because sand and other particles have gotten stuck in the void spaces of the PC over time, so an accurate reading is hard to obtain. Although maintenance will be a contributing factor to cost efficiency later in the research, it is not something of concern for the infiltration test results.

The materials necessary for this test include an infiltration ring, a balance accurate to 10 grams, a container for water, a stop watch accurate to 0.1 seconds, plumber's putty meeting specification C920 or Federal Specification A-A-3110, and potable water (ASTM International, 2009). The infiltration ring is the most specific out of the materials for this test and needs to be standardized in order for this test to be valid. According to ASTM International, it is a cylindrical ring open at both ends. The ring shall be water tight and sufficiently rigid to retain its shape when filled with water. The ring shall have a diameter of 300 millimeters and should be within 10 millimeters in accuracy. The ring should also have a minimum height of 50 millimeters. The reason the ring has to be standardized is to have an equal volume of water over a standard area, therefore reducing error. For instance, if a ring were to be taller and thinner, there will be more pressure pushing the water through the void space of the concrete, therefore giving a skewed rate of infiltration.

Figure 8. Infiltration Ring (Boogaard, 2014)

The water container does not have any strict specifications other than having a minimum volume of at least 20 Liters. The volume of the container is important due to the fact that there needs to be enough water to pour into the ring so that the infiltration is controlled and continuous.

The test must be carried out 24 hours after the last precipitation and should be conducted in multiple locations. The number of locations is usually at the request of the purchaser of testing services, so since the tests were conducted purely for research, five test locations were used. The procedure for the test is taken from the ASTM designation: C1701/C1701M-09 and is as follows.

Infiltration Ring Installation

1. Clean the concrete surface by sweeping off trash, debris, and other non-seated materials.

2. Apply plumbers putty around the bottom edge of the ring and place the ring onto the pervious concrete surface being tested and press the putty into the surface and around the bottom edge of the ring to create a watertight seal.

Prewetting

1. Pour water into the ring at a rate sufficient to maintain a head between two marked lines at a distance of 10 and 15 millimeters from the bottom of the ring. Use a total of 3.60 kg of water within 0.05 kg.
2. Begin timing as soon as the water impacts the pervious concrete surface. Stop timing when free water is no longer present on the pervious surface. Record the amount of elapsed time to the nearest 0.1 second.

Test

1. The test shall be started within 2 minutes after the completion of the prewetting.
2. If the elapsed time in the prewetting stage is less than 30 seconds, then use a total of 18 kilograms within 0.05 kg of water. If the elapsed time in the prewetting stage is greater than or equal to 30 seconds, then use a total of 3.6 kg within 0.05 kg of water. Record the weight of water to the nearest 10 grams.
3. Pour the water into the ring at a rate sufficient to maintain a head between the two marked lines and until the measured amount of water has been used.
4. Begin timing as soon as the water impacts the pervious concrete surface. Stop timing when free water is no longer present on the pervious surface. Record the test duration to the nearest 0.1 second.

   The test procedure was repeated in its entirety at the four other locations around the parking lot, and an average was taken from five infiltration results.

The calculations for this test are very simple and straightforward. Once the test procedure was carried out, the infiltration rate (I) using the formula,

$$I = \frac{K*M}{(D^2*t)} \quad \text{(Eq. 10)}$$

where I is in units of mm/hr, M is the mass of the infiltrated water in kilograms, D is the diameter of the infiltration ring in millimeters, t is the time required for the measured amount of water to infiltrate the concrete, and K is a factor in units of (mm^3*s)/(kg*hr) used to convert the recorded data to infiltration rate units.

Once this calculation was completed, a more accurate infiltration estimate was made for the idealized pervious concrete in the Law School parking lot. The idealized lot had an average infiltration rate of around 610 inches per hour which qualifies the surface to have a runoff coefficient between 0.05 and 0.1 according to the Lemming, Malcom and Tennis article (2007), *Hydrologic Design of Pervious Concrete.* This same source quotes that the curve number for PC is 36 for the given infiltration rate. This information can be found in the Appendix under Tables 14 and 17. Since pervious pavement is so new, there are no regulations stating a minimum rate of infiltration. Nowhere in the Oxford City Ordinances is pervious pavement mentioned, so this value was not obtained to see if the mix design meets minimum specifications, but the value was used to achieve a better understanding of pervious pavements. The rate also allows for a ballpark estimate since there are such a wide variety of pervious concrete types.

3.4 Drainage Pipe Estimation

As explained in the Literature Review, the calculation for the time of concentration makes calculations rather complicated, so an iterative process was used for calculations. A Microsoft Excel workbook was created to be a tool for finding these different values. This workbook falls under each of the steps explained in this chapter, and shows the last iterative process for the parking lot with both PC and asphalt. The final steps of the all-asphaltic parking lot are also shown in this chapter for comparison. However, the rest of the work for all asphalt can be found under Tables 18 through 22 in the Appendix. The chart can be explained with the following structure. A layout of the sewer numbers can be found in the drawings for the Law School located in Chapter 2 under Figure 7. Columns A through X show the calculations made for pipe size estimations.

A. The sewer names are predetermined using the Law School drawings in Figure 7 in the previous chpater. The total value labels are listed under the sewer being analyzed in the case that a sewer has multiple subcatchments.
B. The length of the pipe was approximately measured using a ruler from the same Law School drawings.
C. The slope of the pipe was found by estimating the elevation difference from the uphill end of the pipe to the downhill end using the same figure as the first two columns and dividing the found height difference by the length.
D. The total area drained by a sewer is the sum of all the subcatchments for the particular sewer listed in column E.

E. The incremental subcatchment that drain directly into the sewer being analyzed was found using the SWMM picture found in Figure 4 in Chapter 2.

F. The area of the incremental subcatchment identified in column E.

Table 3. Calculations for Columns A through F in Lot with PC

	A	B	C	D	E	F
1	**Sewer**	**Length Pipe (ft)**	**Slope**	**Total Area (ac)**	**Catchment**	**Area (ac)**
2	**79**	**50**	**0.01**	**0.218**	**Grass 1**	**0.218**
3	80	81.25	0.03		Concrete 1	0.025
4					79	
5	**Total @ 80**			**0.243**		
6	81	181.25	0.01		Pervious 1	0.038
7					80	
8	**Total @81**			**0.28**		
9	**82**	**81.25**	**0.03**	**0.60**	**Grass 2**	**0.600**
10	83	50	0.03		Concrete 2	0.050
11					Grass 3	0.116
12					Asphalt 2	0.180
13					Pervious 2	0.080
14					81	
15					82	
16	**Total @ 83**			**1.31**		
17	84	100.00	0.04	Junction	N/A	
18	85	37.5	0.03		Concrete 3	0.030
19					Asphalt 1	0.200
20					Pervious 3	0.063
21	**Total @ 85**			**1.600**		
22	86	37.5	0.04	Junction	83	
23					85	
24	87	25.00	0.03	N/A	N/A	N/A
25	88			N/A	N/A	N/A

G. The value of the runoff coefficient for each subcatchment is based off a 25 year storm and was taken from Tables 13 and 14 in the Appendix. Note that the runoff coefficients found in Table 13 are values based on the standards used by the City of Austin, Texas. In order to compare a lot with pervious pavement, and a lot with only asphalt, the C values for the pervious catchments in Column E were changed to C values for asphalt. The excel workbook then updates all values and the results can be compared. The final results for pipe size estimates can be found in the last iteration for an all-asphaltic parking lot seen in Table 8 in this chapter.

H. The product of columns F and G.

I. The summation of CA for all the areas drained by that sewer is equal to sum of the value in Column I for the sewer directly upstream and the values in Column H for the subcatchment areas draining directly into that sewer.

J. The inlet time for the subcatchment drained is “the overland flow inlet time if the upstream subcatchment is no more than one sewer away from the sewer being designed; otherwise it is the total flow time to the entrance of the immediate upstream sewer” (Mays, 2011). This value was found using the SCS lag equation.

K. The upstream flow time is the sewer flow time of the immediate upstream sewer as given in Column W.

Table 4. Calculations for Columns G to K for Lot with PC

	G	H	I	J	K
1	**C (25 yr)**	**CA**	**Sum CA**	**Inlet Time**	**Upstream Flow Time**
2	**0.290**	**0.063**	**0.063**	**4.39**	**0**
3	0.880	0.022		1.02	0
4				4.39	0.75
5			**0.085**		
6	0.075	0.003		7.20	0
7				1.02	1.00
8			**0.088**		
9	**0.290**	**0.174**	**0.174**	**5.32**	**0**
10	0.880	0.044		5.83	0
11	0.290	0.034			0
12	0.860	0.155			0
13	0.075	0.006			0
14				7.20	2.71
15				5.32	0.33
16			**0.501**		
17			**0.501**		0
18	0.880	0.026		3.10	0
19	0.860	0.172			0
20	0.075	0.005			0
21			**0.203**		
22				5.83	0.16
23			**0.704**	3.10	0.06
24					0
25					0

L. The length of the watershed is the longest flow path of water in the subcatchment and was estimated using the scale found in the Law School drawings and the watershed in Figure 7 of Chapter 2.

M. The SCS runoff Curve Number was found using Tables 16 and 17 of the Appendix. The numbers were computed assuming that 100% of runoff from impervious areas is directly connected to a drainage system. These values are used for the design of temporary measures during grading and construction. In the event that a sewer collected runoff from multiple subcatchments with different curve number values, a weighted average was taken from the multiple subcatchments and displayed in the total values row. The curve numbers for the pervious concrete sections were changed to asphaltic values for comparison like the C values above.

N. The average watershed slope was estimated using the elevation difference found in Figure 7 in the previous chapter and dividing that value by the length in Column L.

O. The t_c for iteration 1 was computed using the SCS lag equation (U.S. Soil Conservation Service, 1975).

$$t_c = \frac{100L^{0.8}[\left(\frac{1000}{CN}\right)-9]^{0.7}}{1900S^{0.5}} \qquad \text{(Eq. 11)}$$

L is defined as the hydraulic length of the watershed (i.e. the longest flow path) in feet. CN is the SCS runoff curve number, which was found from Table 16 and 17 in the Appendix, and S is the average watershed slope in percentage. L and S were computed using the elevations listed in Figure 7 in Chapter 2. The second iteration used an updated time of concentration that was equal to the sum of the inlet time and the upstream flow time found from the first iteration. The third iteration used the same process but took numbers from iteration 2.

P. The rainfall duration was assumed to be the longest time of concentration of different flow paths to arrive at the entrance of the sewer being considered. In other words, it was taken from the largest value in Column O for the particular sewer.

Q. Since Table 15 in the Appendix does not provide 25 year precipitation intensities for the rainfall durations in Column P, the intensities must be found through extrapolation. A graph was made analyzing storm durations against the intensity values given in Table 5 up to a 96-hour storm. This created an exponential curve from which an equation could be obtained. The graph can be seen in Figure 8 in the Appendix. In the equation below, y represents the intensity of the storm in inches per hour and x represents the time duration in minutes.

$$y = 37.262x^{-0.67} \qquad \text{(Eq. 12)}$$

Table 5. Calculations for Columns L through Q for Lot with PC

	L	M	N	O	P	Q
1	**L Watershed (ft)**	**CN**	**S (%)**	**tc (min)**	**td (min)**	**I (in/hr)**
2	**150.00**	**61.00**	**7.16**	**4.39**	**4.39**	**13.82**
3	162.50	98.00	11.96	1.02	5.14	12.44
4				5.14		
5						
6	87.50	36.00	4.15	7.20	7.20	9.93
7				2.02		
8						
9	**200.00**	**61.00**	**7.75**	**5.32**	**5.32**	**12.16**
10	175.00	98.00	2.29	5.83	9.92	8.01
11		61.00				
12		98.00				
13		36.00				
14				9.92		
15				5.65		
16		**76.28**				
17					**9.92**	**8.01**
18	162.5	98.00	4.22	3.10	3.10	17.45
19		98.00				
20		36.00				
21		**84.67**				
22				6.00	6.00	11.22
23				3.16		
24						
25						

R. The design discharge was computed using the Rational Method (i.e. the product of Column I and Q). Since Column I is the sum of the individual surface areas in each subcatchment, the fact that the runoff might flow over different surfaces was taken into consideration.

S. The required sewer diameter was computed using Manning's equation.

$$D = \left(\frac{m_D Q n}{\sqrt{S_0}}\right)^{3/8} \qquad \text{(Eq. 13)}$$

The variable m_D is 2.16 for U.S. customary units, Q is the value from Column R, n is 0.011 for HDPE pipes, and S_0 is the slope from Column C.

T. The Diameter in Column S is given in feet, so to convert this value to a practical unit, Column S was multiplied by 12 to put it into inches.

U. The nearest commercial nominal pipe size that is not smaller than the computed size is adopted from the pipe sizes found in the City of Rockville, MD cost report.

Table 6. Calculations for Columns R through U for Lot with PC

	R	S	T	U
1	Qp (cfs)	Computed Diameter (ft)	Computed Diameter (in)	Pipe Size (in)
2	0.874	0.63	7.52	12.00
3				
4				
5	1.060	0.50	5.97	12.00
6				
7				
8	0.874	0.55	6.60	12.00
9	2.117	0.63	7.51	12.00
10				
11				
12				
13				
14				
15				
16	4.010	0.79	9.50	12.00
17	4.010	0.77	9.21	12.00
18				
19				
20				
21	3.545	0.77	9.28	12.00
22				
23	7.898	0.98	11.76	12.00
24				
25				

V. The flow velocity was computed by dividing the flow rate in Column R by the area of the commercial pipe using the diameter from Column U.

W. The sewer flow time was computed by dividing the length of the pipe by the flow velocity (i.e. divided Column B by Column V).

X. The price of the pipe was computed by multiplying the price for the diameter of the pipe in dollars per linear foot by the length of that section of the pipe. The reference prices for the pipes were found in a price estimate article by the City of

Rockville, MD. Price adjustments were found in the R.S. Means Construction Cost Data book to adjust the prices to Tupelo, MS. The table for this can be found in the Appendix in Table 23.

Table 7. Calculations for Columns V through X for Lot with PC

	V	W	X	Y
1	Flow Velocity (fps)	Sewer Flow Time (min)	Price of Pipe ($)	
2	1.11	0.75	1975.50	
3				
4				
5	1.35	1.00	3,210.19	
6				
7				
8	1.11	2.71	7,161.19	
9	2.70	0.50	3,210.19	
10				
11				
12				
13				
14				
15				
16	5.11	0.16	1,975.50	
17	5.11	0.33	3,951.00	
18				
19				
20				
21	4.51	0.14	1,481.63	
22				
23	10.06	0.06	2,469.38	
24			25,434.56	Total

Three iterations of this 24-step process were conducted because the sewer flow time changed very little from iteration 2 to iteration 3. This means that sufficient accuracy of the times taken from the last iteration can be assumed. The reason two different workbooks of these calculations were made was to compare the pipe sizes of the parking lot with pervious concrete and asphalt as it was constructed, and a parking lot if no pervious concrete was used. The situation of a parking lot with all pervious concrete was not considered because it is an unreasonable design. The calculations for the all-asphaltic parking lot can be found in Tables 18 through 22 in the Appendix, but the final page of the calculations will be shown so that a comparison of pipe pricing can be made.

Table 8. Calculations for Columns V through X for the All Asphaltic Parking Lot for Comparison

	V	W	X	Y
1	Flow Velocity (fps)	Sewer Flow Time (min)	Price of Pipe ($)	
2	1.11	0.75	1,975.50	
3				
4				
5	1.35	1.00	3,210.19	
6				
7				
8	3.49	0.87	7,161.19	
9	2.70	0.50	3,210.19	
10				
11				
12				
13				
14				
15				
16	8.86	0.09	1,975.50	
17	8.86	0.19	3,951.00	
18				
19				
20				
21	8.35	0.07	1,481.63	
22				
23	10.03	0.06	2,778.13	
24			25,743.31	Total
25				

3.5 Conclusion

After many calculations and manipulations, the data for this project is in values that can easily be interpreted. A numerical comparison can be utilized to answer the original question this thesis posed. The question asked whether pervious pavement can offer a more cost efficient alternative via cheaper materials, decreased storm drainage, or a lower level of maintenance required. The data is now in and so the numbers can be compared in the next chapter.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

Until this chapter, the thesis has been focused on gathering the knowledge and information required to make the most accurate comparison possible between the cost efficiency of PC versus that of asphalt. This chapter will not only attempt to make a straightforward numerical comparison, but it will also discuss and make sense of some of the different outcomes because numerical results proved to not always be possible. A breakdown of how the pavement materials compared will be discussed first, followed by a look at the stormwater drainage differences, and finally, this chapter will wrap up with a summary of a comparison of the required maintenance for each pavement type.

4.2 Materials

One of the most deceiving results from this research ended up being the price difference between the two different pavement materials used. It was inevitable that PC would be more expensive because it is more rare and so fewer manufacturers produce it. Since the price difference of PC is only 35% higher, it didn't seem like the materials would make much difference, especially since PC only makes up a third of the parking lot. The seemingly invisible factor that became apparent during the calculations ended up being the difference in required depth of the two top layers.

The top layer for PC is 4 times deeper than that of asphalt, and over a large area, the depth makes a huge difference. Where PC only makes up a third of the area of the driving surface, it makes up just over 65% of the total volume for the two top layers of the parking lot. This means big price differences since aggregate is priced per volume.

Table 9. Cost Breakdown for Materials

Materials Cost Breakdown			
	Cost ($)	Cost Difference ($)	% Larger
PC and Asphalt	50,490.00	29,640.00	250
All Asphalt	20,850.00		

Since the material for the PC is not only more expensive but also makes up over 65% of the volume of the parking lot, it is much more expensive than the parking lot only paved with asphalt. This price difference might be even greater because the other layers, including the geotextile fabric required for PC, was not factored into this comparison. The cost of PC material makes up about 60% of the total lifetime cost of PC, where as the asphalt top layer only makes up about 34% of its total lifetime costs. The price difference would decrease exponentially if the depth of the PC were not so large. Although the 8-inch depth used at the Law School parking lot is not required, it is a standard depth for pervious pavements so it will be assumed that the depth cannot be decreased.

When the research first began, the cost of materials was an afterthought, however, it has proved to be a legitimate factor in determining the price difference between the two different parking lots. Being able to actually put a value to this comparison is truly eye opening because it is very well known that PC is expensive relative to asphalt, but only the few contractors who have worked on PC around the Southeast have a grasp of exactly how great the difference is. The materials were known to make PC less cost effective, but the original rationale was that the difference in pipe sizes required would make PC much more cost effective, dwarfing the difference in materials. The next section makes the comparison to find out of this is true or not.

4.3 Stormwater Drainage

To estimate the required pipe sizes, the rational method estimated the peak runoff rate for each of the two parking lot types. As seen in the Microsoft Excel calculations in the previous chapter, stormwater runoff was indeed decreased by the PC, but this effect on cost turned out to be rather minute. Contractors and engineers around Oxford and the surrounding areas did not have a grasp of how little the runoff difference affected the pipe sizes, but the following data will show just that.

The pervious concrete affects only 5 out of the 8 pipes in the analyzed section of the parking lot. The pipes that remain unaffected take in runoff from a subcatchment uphill of the pervious section. This makes sense but will decrease the price difference between all asphalt and the lot that uses PC. A layout of the lot in Chapter 2 under Figure 7 will further explain this notion. Inlets 81, 83, and 85 are taking in runoff after passing over the PC. This means that pipes 81-83, 83-84, 84-86, 85-86, and 86-87 have a change in diameter. The breakdown of how much these pipes are affected can be seen in the chart below.

Table 10. Computed and Actual Selected Pipe Size Difference

Pipes Size Difference					
	Computed Sizes			Actual Sizes	
Pipe	Lot w/ PC (in)	All Asphalt Lot (in)	% Larger than PC Lot	Lot w/ PC (in)	All Asphalt Lot (in)
81-83	6.60	10.13	53	12	12
83-84	9.50	11.68	23	12	12
84-86	9.21	11.32	23	12	12
85-86	9.28	11.68	16	12	12
86-87	11.76	13.89	18	12	15

A trend develops showing that the percent difference in the pipe sizes decreases, as the pipe requires a larger capacity of runoff. This means that the larger the runoff catchment area, the less of an impact PC will have on pipe sizes. In Dan Brown's article, he claims, "the principal uses for pervious concrete have been for parking lots, low traffic pavements, and pedestrian walkways". This makes sense because larger runoff volumes have greater flow velocities. This means that the runoff will have less time to slow down by infiltrating into the PC.

The difference in price was surprising. The price differences can be seen in Tables 7 and 8 in Chapter 3. The stormwater drainage of the analyzed parking lot, paved only with asphalt is only around $310 more than the lot that is paved with PC. This is a mere 1% increase in price. This result was completely different than the original assumption but eye opening and informative just the same. The fact that this price difference is so small could be for a couple reasons. The first is that only three pipe sizes were considered for the design with the minimum being 12 inches. The required pipe sizes for the lot with PC were much less than 12 inches, but a 12 inch pipe was used simply because it was the minimum. Price cuts could result if an 8 or 10 inch pipe was the minimum, especially for some of the longer pipes. The second reason is a question of how accurate both the Rational Method and Manning's equation are. The pipes used in the actual design of the lot had a uniform diameter of 18 inches. Cary McGonagill says that contractors use a variety of different methods to estimate stormwater pipe sizes. Just because both the Rational Method and Manning's equation are taught in school does not mean they are the preferred method for a job site. McGonagill continued by saying that many contractors estimate pipe sizes just from experience alone.

Whether they are accurate or not, these two sources of error would not make much of a difference in the price difference. At this point, the inefficiencies in price of PC greatly outweigh the efficiencies as compared to asphalt. After analyzing two aspects of the life of each pavement type, there seem to be no monetary benefits to using PC. The next section dissecting the maintenance costs might be able to swing the pendulum in the other direction.

4.4 Maintenance

There were many potential issues discussed in Chapter 3 with PC that would require maintenance over the lifetime of the pavement, however, the issues were not entirely confirmed because PC has simply not been around long enough for people to study long term. This means that the cost of maintenance for PC will be assumed to be \$0. While this may bring about some sources of error for the comparison, it is accurate in the sense that the University of Mississippi is not putting forth any money to maintain the PC on its campus. The comparison will include just the maintenance costs for asphalt since both parking lots being analyzed have asphaltic sections.

The prices outlined in the Methodology and Data Collection chapter illustrate only one microsurfacing job, however, Jimmy Kendrick suggested that there be two microsurfacing jobs over the life of a pavement, so this cost will double. An illustration of the cost difference for each lot is shown for clarification.

Table 11. Cost Breakdown for the Maintenance of Asphalt for Each Lot Type

Maintenance Cost Breakdown			
	Cost ($)	Cost Difference ($)	% Larger
PC and Aphalt	7,353.00	3,508.00	48
All Asphalt	10,861.00		

Since the microsurfacing job is given in units of cost per square yard, it would be fair to assume that the % increase in cost is directly proportional to the % increase of the area of asphalt used in the lot analyzed with PC to the area of asphalt used for the lot totally paved with asphalt. This assumption is correct since the total area of the parking lot is around 24,000 square feet and there is about 16,000 square feet of asphalt in the lot that utilizes PC. Even though maintenance is the biggest cost advantage PC has over asphalt, it contributes the least towards the total cost over the life of each pavement type. Maintenance is about 10% of the total costs for the lot with PC and about 20% of the cost for the lot with only asphalt.

While these numbers for maintenance may not be 100% accurate, they provide a legitimate basis for comparison. Even though PC may have a plethora of issues, work being done around the world is very recent, so little is known about permeable surfaces. It is not completely inaccurate to assume that nothing will be done to maintain the PC because up to this point, no maintenance methods have been applied anywhere except for an occasional vacuum of the pavement to clear clogging.

4.5 Conclusion

After the comparisons in each of the three different categories were made, PC proved to be cost efficient in two of the three categories, drainage pipe sizes and maintenance. The problem is that the high cost of the materials for PC vastly outweighs the two categories of lower cost. A breakdown of the total lifetime price contributions is shown in Table 12 to illustrate a final cost comparison.

Table 12. Breakdown of the Total Lifetime Costs for Each Parking Lot Type

Total Lifetime Costs for 25 Years				
	Costs ($)		Percent of Total (%)	
	PC/Asphalt	All Asphalt	PC/Asphalt	All Asphalt
Materials	50,490.00	20,855.00	60	36
Stormwater Pipes	25,435.00	25,743.00	30	45
Maintenance	7,353.00	10,861.00	10	19
Total:	83,278.00	57,459.00	100	100

Table 12 shows that the lot made up of both PC and asphalt costs about $25,820 more than an all-asphaltic lot. This means that utilizing PC will increase the total expense by about 45%. The question now must be addressed of whether this difference is worth it or not. The University architect pointed out that Facilities Planning was well aware that using PC would be more expensive, but he made it clear that he was a big proponent of using green alternatives and giving back to the environment. Unfortunately, there are not many systems that are both green and cost efficient. There is a clear trade off that must be made. In the grand scheme of the entire Law School project, however, the cost of the parking lot was most likely a very minimal expense.

CHAPTER 5: CONCLUSION

This thesis sought to uncover the mystery that surrounded pervious concrete. So few projects around the continental United States use pervious pavements, which begs the question, are contractors and clients are simply unfamiliar with the option, or is the concrete just fiscally irresponsible to use? The answer seems to be that pervious concrete is both widely unknown and has little monetary value. Cary McGonagill claims that less than 1% of pavement projects in Mississippi and surrounding states use permeable pavements. This pavement type and other green alternatives in this country are mainly started in the Western and Eastern states, so it takes a while for the movement to reach the rest of the country. Travel is slow because projects are mainly driven by low cost options that still get the job done. Asphalt is both low cost and people understand the benefits and drawbacks to it. A client would have to intentionally feel an altruistic need to give back to the environment or feel pressure from an outside source to use alternatives to solve an ongoing problem. Along with giving back and being green, another goal for the University was to be a good neighbor by controlling excess runoff with pervious concrete. As far as the monetary values of PC, this research shows that it has more benefits than drawbacks, but the cost of materials vastly outweighs any of the benefits it might have. There were points of uncertainty and error along the way, so much can be done to improve the comparison of pervious concrete and asphalt.

<u>Summary of Main Points:</u>

- PC is both widely unknown and holds little monetary value

- PC has more benefits than asphalt, but the cost difference of materials outweighs these benefits

With so little known about pervious pavement, the research unveiled a seemingly unending list of further questions and an even longer list for further evaluation. The first and most disappointing thing that could not be addressed for this research was the comparison of installation techniques. Being able to breakdown the details for this comparison would have made the scope of the research a lot more well rounded. Looking at both PC and asphalt over a full lifetime was a large goal that was hindered by the failure of obtaining installation detailing. Along with the construction, not looking at the prices of more than just the top layer for each pavement provided sources of error. Since the base layers for each type were not the same, a more in-depth look should have been taken to point out the differences and how they affected the total price differences. A better understanding of PC maintenance could have also made a stronger comparison. Vacuuming is a minimal contribution, so things like repairing the surface structure and understanding base failures would go a long way for the legitimacy of PC. The last question that arose stemmed from the accuracy of the Rational Method in real world applications. A comparison of different pipe size estimation methods might shed some light on how reliable the Rational Method is. Most all of these questions and concerns could be thesis topics of their own, so if further research on this topic is taken up, these are the questions and concerns that need to be addressed.

<u>Summary of Sources of Error:</u>

- A price comparison of installation techniques was not addressed in this research

- The prices of just the top layer of materials used were compared
- Maintenance of PC was not addressed in the research
- Only one method for pipe size estimation was used

The future for permeable pavement seems bright because it is still in its infancy. Further research and development could change the course of this pavement type drastically. If the strength of PC was higher, not as much top surface would have to be used which would significantly decrease the price. As of right now, PC only makes sense for small projects, but it is only a matter of time before a high strength permeable pavement is developed and used all around the world.

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APPENDIX

Table 13. Table of C Values (Mays, 2011)

Table 15.2.3 Runoff Coefficients for Use in the Rational Method

Character of surface	Return period (years)						
	2	5	10	25	50	100	500
Developed							
Asphaltic	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete/roof	0.75	0.80	0.83	0.88	0.92	0.97	1.00
Grass areas (lawns, parks, etc.)							
Poor condition (grass cover less than 50% of the area)							
Flat, 0–2%	0.32	0.34	0.37	0.40	0.44	0.47	0.58
Average, 2–7%	0.37	0.40	0.43	0.46	0.49	0.53	0.61
Steep, over 7%	0.40	0.43	0.45	0.49	0.52	0.55	0.62
Fair condition (grass cover 50% to 75% of the area)							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Good condition (grass cover larger than 75% of the area)							
Flat, 0–2%	0.21	0.23	0.25	0.29	0.32	0.36	0.49
Average, 2–7%	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Steep, over 7%	0.34	0.37	0.40	0.44	0.47	0.51	0.58
Undeveloped							
Cultivated land							
Flat, 0–2%	0.31	0.34	0.36	0.40	0.43	0.47	0.57
Average, 2–7%	0.35	0.38	0.41	0.44	0.48	0.51	0.60
Steep, over 7%	0.39	0.42	0.44	0.48	0.51	0.54	0.61
Pasture/range							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Forest/woodlands							
Flat, 0–2%	0.20	0.25	0.28	0.31	0.35	0.39	0.48
Average, 2–7%	0.31	0.34	0.36	0.40	0.43	0.47	0.56
Steep, over 7%	0.35	0.39	0.41	0.45	0.48	0.52	0.58

Note: The values in the table are the standards used by the City of Austin, Texas.

Source: Chow, Maidment, and Mays (1988).

Table 14. C Values for Pervious Concrete (Lemming, 2007)

Infiltration rate in./ (*cm/h*)	Runoff coefficient (rational method *C*)
1 in./h (*2.5 cm/h*) or greater	0.05 to 0.10
0.5 to 1 in./h (*1.3 to 2.5 cm/h*)	0.10 to 0.20
0.1 to 0.5 in./h (*0.3 to 1.3 cm/h*)	0.20 to 0.35

Table 15. NOAA Intensity Duration Chart (NWS)

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	5.45 (4.79-6.28)	6.18 (5.44-7.13)	7.42 (6.49-8.56)	8.46 (7.38-9.79)	9.94 (8.48-11.7)	11.1 (9.32-13.2)	12.3 (10.1-14.9)	13.5 (10.8-16.6)	15.2 (11.8-19.0)	16.5 (12.5-20.8)
10-min	3.99 (3.51-4.60)	4.53 (3.98-5.22)	5.42 (4.76-6.26)	6.19 (5.41-7.16)	7.27 (6.21-8.60)	8.13 (6.82-9.68)	9.01 (7.37-10.9)	9.91 (7.88-12.2)	11.1 (8.61-13.9)	12.1 (9.16-15.3)
15-min	3.24 (2.85-3.74)	3.68 (3.24-4.24)	4.41 (3.87-5.09)	5.03 (4.40-5.83)	5.91 (5.05-6.99)	6.61 (5.55-7.88)	7.32 (6.00-8.85)	8.06 (6.41-9.91)	9.06 (7.00-11.3)	9.84 (7.45-12.4)
30-min	2.31 (2.03-2.66)	2.62 (2.31-3.03)	3.15 (2.76-3.64)	3.60 (3.14-4.17)	4.24 (3.62-5.01)	4.74 (3.98-5.64)	5.25 (4.30-6.35)	5.78 (4.59-7.10)	6.50 (5.02-8.12)	7.06 (5.34-8.89)
60-min	1.51 (1.33-1.75)	1.72 (1.51-1.98)	2.06 (1.81-2.38)	2.36 (2.06-2.73)	2.78 (2.37-3.28)	3.11 (2.61-3.70)	3.44 (2.82-4.17)	3.80 (3.02-4.67)	4.28 (3.30-5.34)	4.65 (3.52-5.86)
2-hr	0.937 (0.828-1.07)	1.06 (0.940-1.22)	1.28 (1.13-1.46)	1.46 (1.28-1.68)	1.72 (1.48-2.02)	1.92 (1.62-2.28)	2.13 (1.76-2.56)	2.35 (1.88-2.87)	2.65 (2.06-3.29)	2.88 (2.20-3.61)
3-hr	0.704 (0.625-0.803)	0.800 (0.709-0.911)	0.960 (0.849-1.10)	1.10 (0.966-1.26)	1.29 (1.11-1.51)	1.45 (1.23-1.71)	1.61 (1.33-1.92)	1.77 (1.43-2.16)	2.00 (1.56-2.48)	2.18 (1.67-2.72)
6-hr	0.430 (0.383-0.486)	0.489 (0.436-0.554)	0.590 (0.524-0.669)	0.676 (0.598-0.768)	0.798 (0.692-0.928)	0.895 (0.763-1.05)	0.995 (0.828-1.18)	1.10 (0.888-1.33)	1.24 (0.975-1.53)	1.35 (1.04-1.68)
12-hr	0.258 (0.231-0.289)	0.295 (0.264-0.332)	0.358 (0.320-0.402)	0.411 (0.366-0.464)	0.486 (0.424-0.561)	0.546 (0.468-0.635)	0.608 (0.509-0.718)	0.672 (0.546-0.806)	0.758 (0.600-0.926)	0.826 (0.640-1.02)

Table 16. Curve Number Chart (Mays, 2011)

Land use description	Average % impervious[b]	A	B	C	D
		Curve numbers for hydrologic soil group			
Fully developed urban areas[a] (vegetation established)					
Lawns, open spaces, parks, golf courses, cemeteries, etc.					
Good condition; grass cover on 75% or more of the area		39	61	74	80
Fair condition; grass cover on 50% to 75% of the area		49	69	79	84
Poor condition; grass cover on 50% or less of the area		68	79	86	89
Paved parking lots, roofs, driveways, etc.		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89
Paved with open ditches		83	89	92	93
Commercial and business areas	85	89	92	94	95
Industrial districts	72	81	88	91	93
Row houses, town houses, and residential with lot sizes 1/8 acre or less	65	77	85	90	92
Residential: average lot size					
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acre	12	46	65	77	82
Developing urban areas[c] (no vegetation established)					
Newly graded area		77	86	91	94

Table 17. Curve Numbers for Pervious Concrete (Lemming, 2007)

		Equivalent CN			
		2-year storm: 4 in. (*100 mm*)		10-year storm: 6 in. (*150 mm*)	
Case	Infiltration rate	no base	8 in. (*200 mm*) base	no base	8 in. (*200 mm*) base
1	1.0 in./h (*2.5 cm/h*)	49	< 36*	49	< 36*
2	0.5 in./h (*1.3 cm/h*)	58	< 36*	55	< 36*
3	0.1 in./h (*0.3 cm/h*)	76	47	77	61
4	0.01 in./h (*0.03 cm/h*)	91	73	91	77

* Calculated values of the equivalent Curve Number should not be given below about 36.

Table 18. Calculations for Pipe Sizes All Asphalt Columns A to E

	A	B	C	D	E
1	**Sewer**	**Length Pipe (ft)**	**Slope**	**Total Area (ac)**	**Catchment**
2	**79**	**50**	**0.01**	**0.218**	**Grass 1**
3	80	81.25	0.03		Concrtete 1
4					79
5	**Total @ 80**			**0.243**	
6	81	181.25	0.01		Idealized asphalt 1
7					80
8	**Total @81**			**0.28**	
9	**82**	**81.25**	**0.03**	**0.60**	**Grass 2**
10	83	50	0.03		Concrete 2
11					Grass 3
12					Asphalt 2
13					Idealized Asphalt 2
14					81
15					82
16	**Total @ 83**			**1.31**	
17	84	100.00	0.04	Junction	N/A
18	85	37.5	0.03		Concrete 3
19					Asphalt 1
20					Idealized Asphalt 3
21	**Total @ 85**			**1.600**	
22	86	37.5	0.04	Junction	83
23					85
24	87	25.00	0.03	N/A	N/A
25	88			N/A	N/A

Table 19. Calculations for Pipe Sizes All Asphalt Columns F to K

	F	G	H	I	J	K
1	**Area (ac)**	**C (25 yr)**	**CA**	**Sum CA**	**Inlet Time**	**Upstream Flow Time**
2	**0.218**	**0.290**	**0.063**	**0.063**	**4.39**	**0**
3	0.025	0.880	0.022		1.02	0
4					4.39	0.75
5				**0.085**		
6	0.038	0.860	0.033		1.05	0
7					1.02	1.00
8				**0.118**		
9	**0.600**	**0.290**	**0.174**	**0.174**	**5.32**	**0**
10	0.050	0.880	0.044		3.97	0
11	0.116	0.290	0.034			0
12	0.180	0.860	0.155			0
13	0.080	0.860	0.069			0
14					1.05	0.66
15					5.32	0.30
16		**0.230**		**0.593**		
17				**0.593**		0
18	0.030	0.880	0.026		1.71	0
19	0.200	0.860	0.172			0
20	0.063	0.860	0.054			0
21		**0.158**		**0.253**		
22	N/A				3.97	0.09
23				**0.846**	1.71	0.05
24	N/A					0
25	N/A					0

Table 20. Calculations for Pipe Sizes All Asphalt Columns L to Q

	L	M	N	O	P	Q
1	**L Watershed (ft)**	**CN**	**S (%)**	**tc (min)**	**td (min)**	**I (in/hr)**
2	**150.00**	**61.00**	**7.16**	**4.39**	**4.39**	**13.82**
3	162.50	98.00	11.96	1.02	5.14	12.44
4				5.14		
5						
6	87.50	98.00	4.15	1.05	2.02	23.26
7				2.02		
8						
9	**200.00**	**61.00**	**7.75**	**5.32**	**5.32**	**12.16**
10	175.00	98.00	2.29	3.97	5.62	11.73
11		61.00				
12		98.00				
13		98.00				
14				1.72		
15				5.62		
16		**87.92**				
17					**5.62**	**11.73**
18	162.5	98.00	4.22	1.71	1.71	25.97
19		98.00				
20		98.00				
21		**98.00**				
22				4.07	4.07	14.56
23				1.76		
24						
25						

Table 21. Calculations for Pipe Sizes All Asphalt Columns R to U

	R	S	T	U
1	Qp (cfs)	Computed Diameter (ft)	Computed Diameter (in)	Pipe Size (in)
2	0.874	0.63	7.52	12.00
3				
4				
5	1.060	0.50	5.97	12.00
6				
7				
8	2.742	0.84	10.13	12.00
9	2.117	0.63	7.51	12.00
10				
11				
12				
13				
14				
15				
16	6.955	0.97	11.68	12.00
17	6.955	0.94	11.32	12.00
18				
19				
20				
21	6.560	0.97	11.68	12.00
22				
23	12.31	1.16	13.89	15.00
24				
25				

Table 22. Calculations for Pipe Sizes All Asphalt Columns V to X

	V	W	X	Y
1	Flow Velocity (fps)	Sewer Flow Time (min)	Price of Pipe ($)	
2	1.11	0.75	1,975.50	
3				
4				
5	1.35	1.00	3,210.19	
6				
7				
8	3.49	0.87	7,161.19	
9	2.70	0.50	3,210.19	
10				
11				
12				
13				
14				
15				
16	8.86	0.09	1,975.50	
17	8.86	0.19	3,951.00	
18				
19				
20				
21	8.35	0.07	1,481.63	
22				
23	10.03	0.06	2,778.13	
24			25,743.31	Total
25				

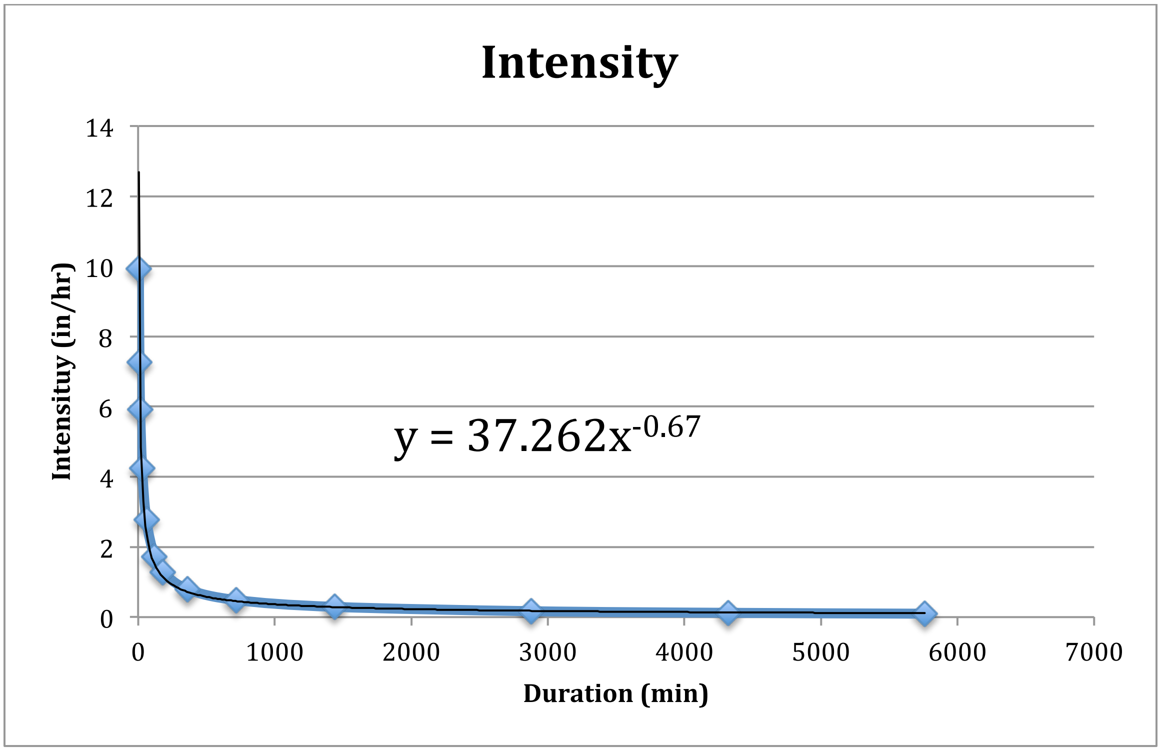

Figure 8. Extrapolation Graph for Rainfall Intensity

Table 23. Pipe Size Price Adjustments

Price Adjustment for Pipe Sizes			
City	**Location Adjustment**	**Pipe Sizes (inches)**	**Prices ($)**
Rockville, MD	0.983	12	40.00
		15	45.00
		18	50.00
Tupelo, MS	0.971	12	39.51
		15	44.45
		18	49.39